Preliminary Investigation of Seasonal flow patterns in the Somali Current and Arabian Sea using a synthesis of Surface Drifter and Satellite Altimeter Data

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LONG-TERM GOALS

To inform strategies for remote deployment of autonomous instrumentation into the maritime piracy zone of the Arabian Sea, where the unsteady monsoon circulation and lack of observations make for one of the most compelling and challenging regions of the world ocean to study.

OBJECTIVES

To characterize the monthly variability of surface currents in the Arabian Sea, where strong Asian monsoon winds seasonally reverse the sense of the basin-wide circulation from cyclonic in boreal winter to anticyclonic in summer.

APPROACH

To analyze and synthesize existing surface drifter and satellite altimeter data. Since the global drifter array became fully realized in 2005 there have been a total of 421 unique drifters in the Arabian Sea, a median of 8 each day.

WORK COMPLETED

The analysis is complete and a paper has been published: Beal, L. M., V. Hormann, R. Lumpkin, & G. R. Foltz (2013) The response of the surface circulation of the Arabian Sea to monsoonal forcing. *J. Phys. Oceanogr.*, 43, 2008-2022, doi: 10.1175/JPO-D-13- 033.1.

RESULTS

Figures 1 and 2 show monthly mean absolute surface currents from drifters, and geostrophic surface currents from a drifter-altimeter synthesis, respectively. We found several features that advance current understanding of the surface circulation in the Arabian Sea. Most significantly, geostrophic northward flow appears along the length of the western boundary, together with a weak anticyclone at 6ºN (a precursor to the Great Whirl) as early as March or April (figure 2). This circulation cannot be explained through Rossby wave adjustment to wind stress curl over the basin interior (e.g. Lighthill, 1969), since it appears one or two months before the southwest monsoon winds appear. Instead, this circulation is

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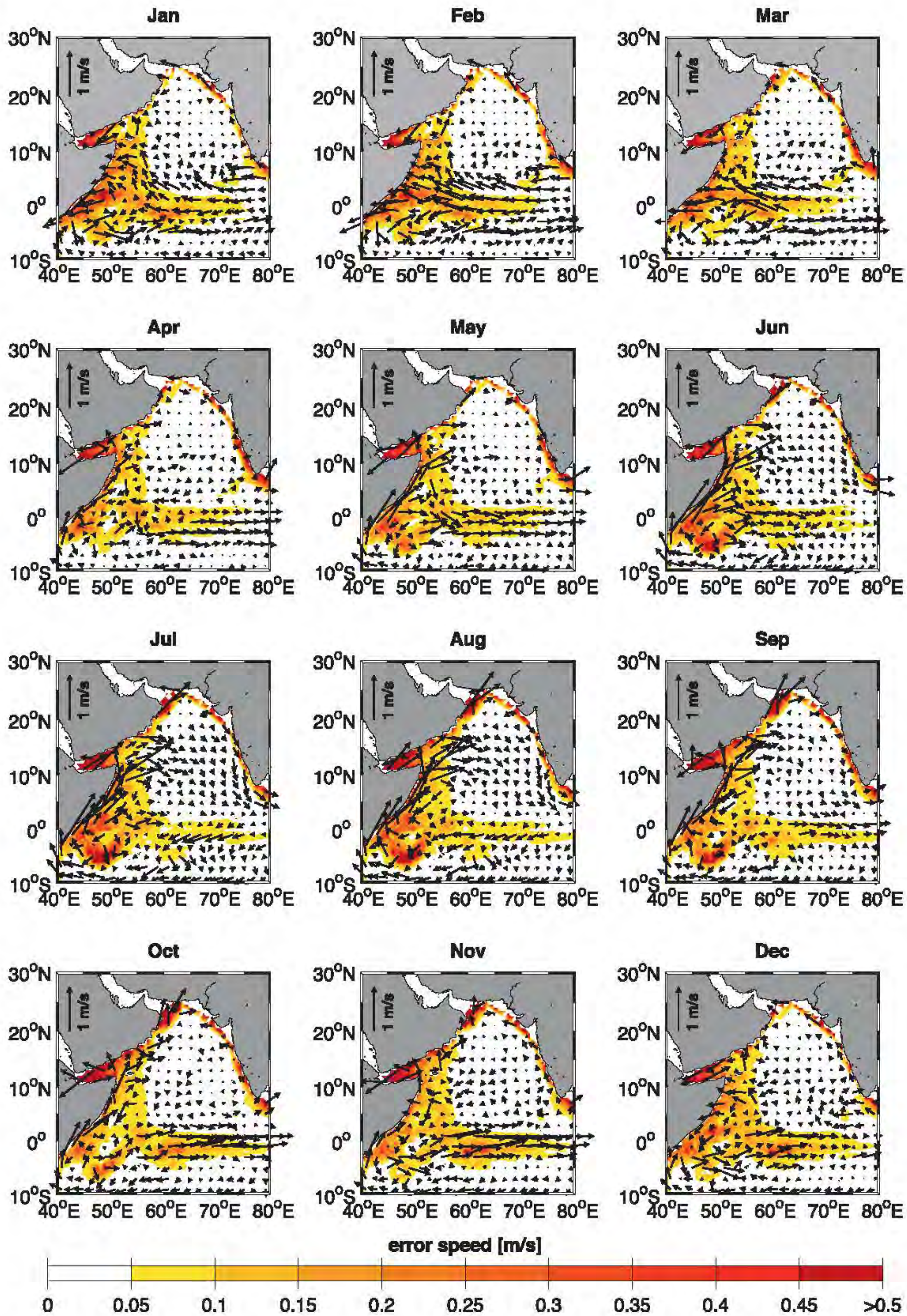

Figure 1: Monthly-mean absolute, near-surface currents (vectors; m/s) and formal error speeds (color shading; m/s) from the drifter climatology. Note strong, northward, cross-equatorial flow in the interior during the northeast monsoon (January-March) and southward cross-equatorial flow during the southwest monsoon (June-August). Landmasses are shaded gray. From Beal et al. (2013).

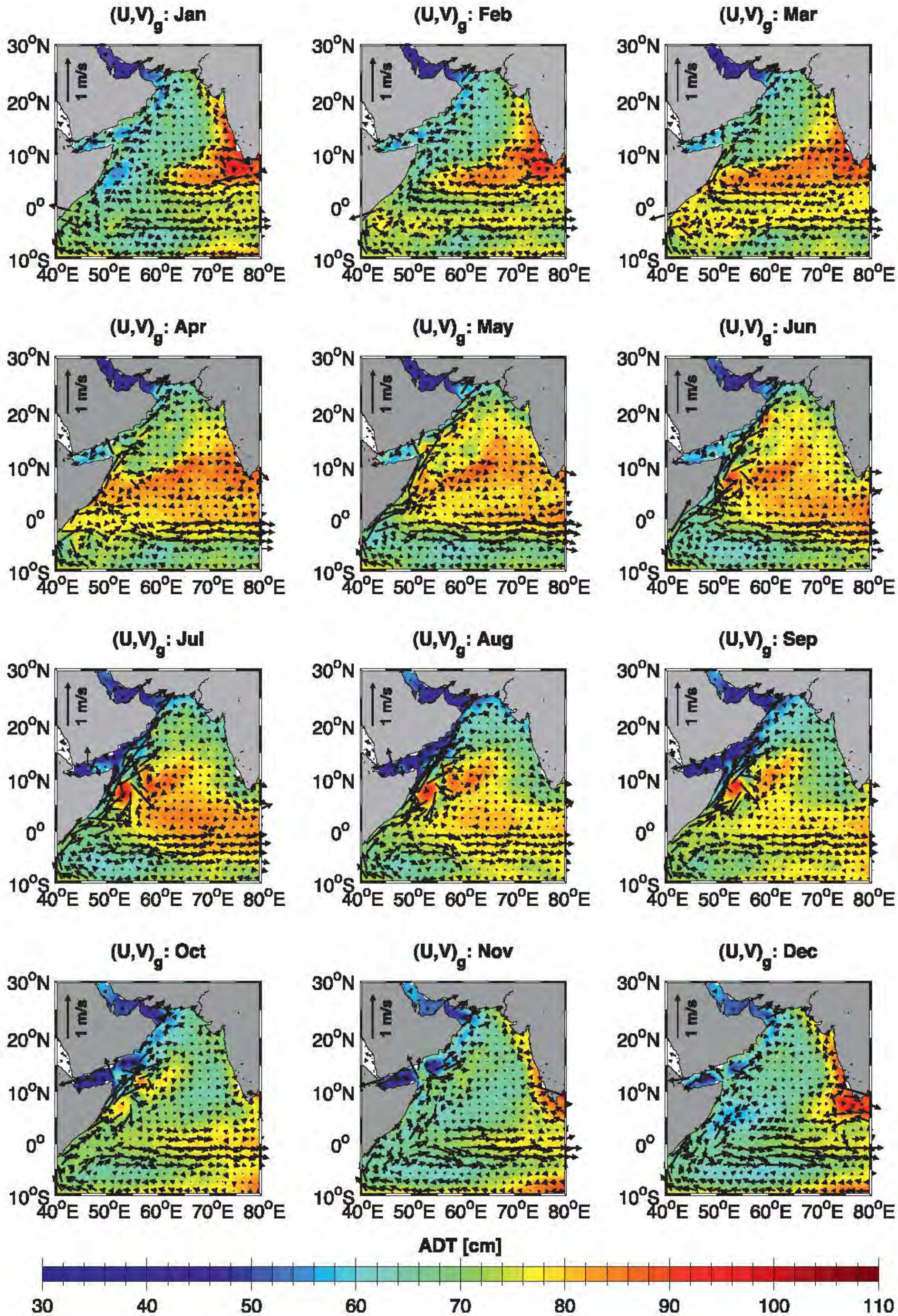

Figure 2: Monthly-mean geostrophic surface currents (vectors; m/s) from the drifter–altimeter synthesis, and absolute dynamic topography (ADT; color shading; cm) from Archiving, Validation, and Interpretation of Satellite Oceanographic data (AVISO). Note the early appearance of the GW, or its precursor, in March, and the year-round SECC. Landmasses are shaded gray. From Beal et al. (2013).

driven by planetary wave adjustment initiated by wind curl forcing during the previous southwest monsoon. Equatorial and coastal Kelvin waves carry the adjustment across the basin and around the rim of the Bay of Bengal to the tip of the Indian continent, where first and second-mode Rossby waves are radiated back into the Arabian Sea (Brandt et al., 2002; Rao et al., 2010). This process leads us to speculate that there is an oceanic mechanism through which one monsoon may precondition the next, leading to predictability. These results also demonstrate the primary importance of planetary waves, rather than the wind, in shaping the surface circulation during the inter-monsoon periods (March-May and September- November).

Second, we found that eastward flow just south of the equator, the South Equatorial Counter Current (SECC), is present year-round, fed by a northward boundary current (East African Coastal Current) (figures 2 and 3). During the southwest monsoon the boundary current overshoots the equator and splits, feeding both northward into the Somali Current and eastward into the SECC by looping back across the equator. This retroflection of the boundary current has been previously identified as the Southern Gyre (e.g. Schott and McCreary, 2001). At the surface, the retroflection is obscured and appears as a closed gyre due to strong, locally wind-driven, cross-equatorial transport (figure 1 and 3).

We constructed an 18-year time-series of SECC strength (not shown) and showed that semiannual variability of the SECC is largely governed by Ekman pumping over the equatorial gyre to the south of the equator. The mean surface velocity of the SECC from this 18-year time period is 0.26 ± 0.22 m/s

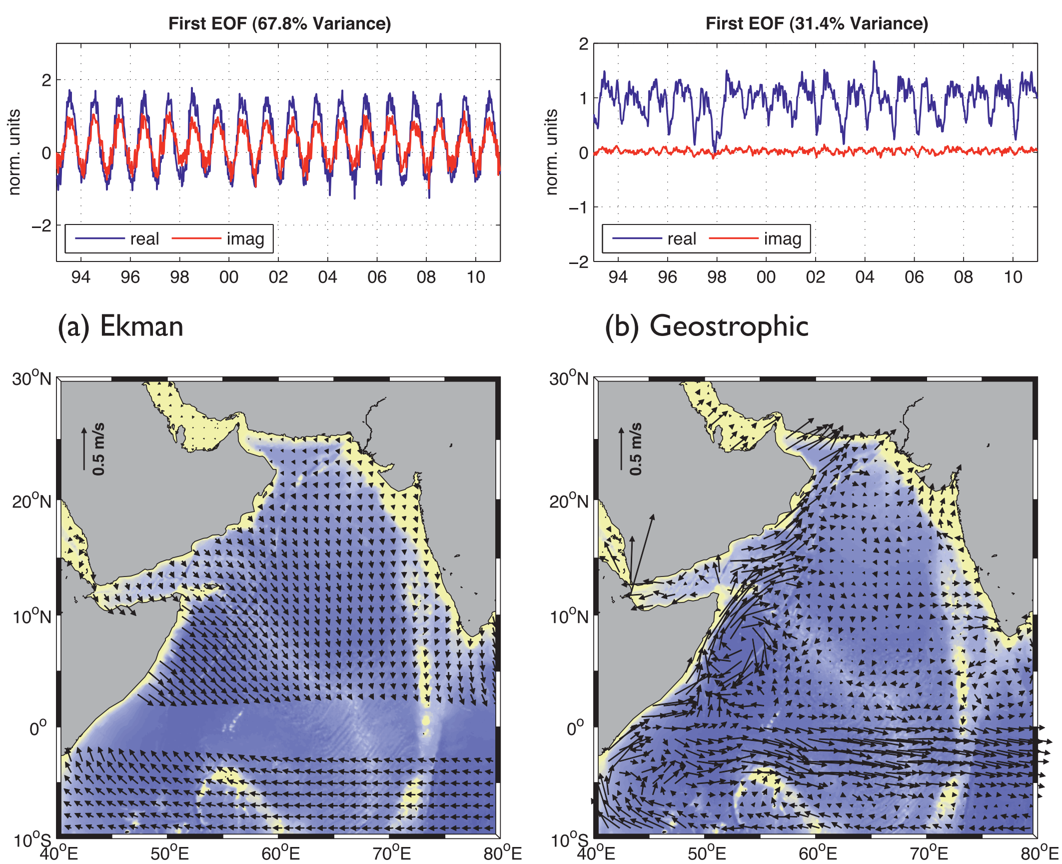

Figure 3: Structure and phase of the dominant modes (complex EOFs) of variance for (a) Ekman and (b) geostrophic velocities. The top panels show the principal component time series and the bottom panels show the spatial amplitudes of the eigenvectors. Ekman velocities are from NCEP–NCAR reanalysis winds and geostrophic velocities are from the drifter–altimeter synthesis. From Beal et al. (2013).

and its mean position is 2.6º ± 1ºS. There are only a handful of events when the SECC reverses, most notably during the 1997/98 El Nino.

Finally, there is broad, strong eastward flow at the mouth of the Gulf of Aden throughout the southwest monsoon (figures 1, 2, and 4). This flow is a result of both local wind forcing and the regional wind stress curl pattern. The Ekman currents flow out of the Gulf of Aden and offshore as a direct response to a split in the axis of the southwest monsoon wind jet over the island of Socotra (figure 4), while broad, northeastward geostrophic flow is set up along the jet axes by the gradient of sea surface height (SSH), which results from the opposing wind stress curls on either side. The effect of the two wind speed maxima is to cause a local high in SSH north of the island of Socotra, setting up eastward geostrophic flow at the mouth of the Gulf of Aden. Hence, Ekman and geostrophic currents combine during the summer monsoon, such that the surface boundary flow diverts offshore as it crosses the mouth of the Gulf of Aden.

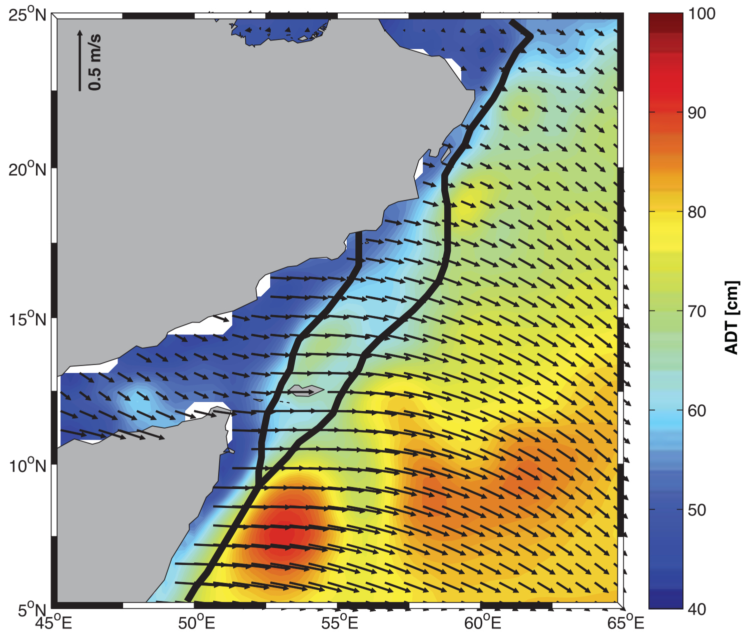

Figure 4: Ekman currents from the NCEP–NCAR reanalysis winds (vectors; m/s), and absolute dynamic topography from AVISO (color shading; cm), with the two axes of the monsoon jet (wind speed maxima) superposed as thick black lines. All data are averaged over June–August. Landmasses are shaded gray. From Beal et al. (2013).

IMPACT/APPLICATIONS

We found that weak basin-wide anticyclonic circulation and a northward boundary flow occur in April, two months before the onset of the southwest monsoon winds. This circulation results from the propagation of Rossby and Kelvin waves around the northern Indian Ocean waveguide, which in turn are initiated by strong downwelling wind curl during the previous southwest monsoon. This interesting observation leads to important impacts concerning predictability. Would the southwest monsoon circulation look the same without the planetary wave feedback mechanism? Does it dampen or enhance interannual or decadal variability of the monsoon circulation? Is it possible that an ocean pathway exists through which one monsoon can precondition the next? For example, for the case of a stronger than normal southwest monsoon, there will tend to be stronger downwelling-favorable wind stress curl in the Arabian Sea, resulting in a larger positive sea level anomaly. This sea level anomaly will propagate around the basin and back to the western Arabian Sea by April of the following year, tending to deepen the thermocline anomalously, which could lead to an increase in SST off the coast of Somalia through a reduction in upwelling. The higher than normal SST may then transfer more moisture to the atmosphere, potentially contributing to stronger Indian summer monsoon rainfall (Izumo et al. 2008). Predictability of monsoon rainfall would be a powerful asset for the inhabitants of the south Asian continent, where the monsoon affects water supply and agriculture.

RELATED PROJECTS

NASCar - Northern Arabian Sea Circulation autonomous research.

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Beal, L. M., V. Hormann, R. Lumpkin, & G. R. Foltz (2013) The response of the surface circulation of the Arabian Sea to monsoonal forcing. *J. Phys. Oceanogr.*, 43, 2008-2022, doi: 10.1175/JPO-D-13- 033.1.